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13. ABSTRACT *(Maximum 200 words)*

Millimeter wave circuits require studies of wave interactions from electromagnetic point of view in the analysis, design and characterizations of circuits, components and systems. In this research, wave interaction issues are central in a number of investigations. The topics studied include active quasi-optical structures for power generation, active integrated antennas for radar, communication and transponders, optical control of remotely located active antennas, and comprehensive electromagnetcis simulation of active microwave and millimeter wave circuit structures. We have accomplished milestones in these subjects. Quasi-optical power combiner has an excellent capability while the electromagnetic simulation enhance the capability of obtaining much more information content than in conventional CAD programs on the physical and dynamic behavior of the circuits.

14. SUBJECT TERMS

Millimeter Waves, Quasi-optical power combining, Active Antennas, CAD

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(1) List of Publications

Journal Papers Published

"Optically Assisted Microwave Active Integrated Antennas," IEICE Transactions on Electronics, Vol.E79-C, No.1, pp.60-67, January 1996, (S. T. Chew, D. T. K. Tong, M. C. Wu and T. Itoh).

"Application of Voltera Series to the Problem of Self-Oscillating Mixer," IEEE Trans. Microwave Theory and Techniques, Vol.44, No. 2, pp.269-274, February 1996, (S. T. Chew and T. Itoh).

"Use of Direct-Modulated/Gain-Switched Optical Links in Monopulse-Type Active Phased Array Systems," IEEE Trans. Microwave Theory and Techniques, Vol.44, No.2, pp.326-330, February 1996, (S. T. Chew, D. T. K. Tong, M. Wu and T. Itoh).

"Modeling of Microwave Active Devices Using the FDTD Analysis Based on the Voltage-Source Approach," IEEE Microwave and Guided Wave Letters, Vol.6, No.5, pp.199-201, May 1996, (C.-N. Kuo, R.-B. Wu, B. Houshmand and T. Itoh).

Conference Papers Published

"A dielectric slab waveguide lens realized from Yagi-Uda slot array antenna elements and microstrip delay lines," National Radio Science Meeting, p.153, January 9-13, 1996, Boulder, CO (A. R. Perkons and T. Itoh).

"An Absorbing Boundary Condition for the FDTD Method using digital Design Technique", Proceedings of ACES, pp.1267-1272, March 18-22, 1996, Monterey, CA, (C-N. Kuo and T. Itoh).

"FDTD Analysis of a Dielectric Leaky-Wave Antenna Using PML," Proceedings of ACES, pp.1004-1007, March 18-22, 1996, Monterey, CA, (M. Chen, B. Houshmand and T. Itoh).

"Recent Advances in Active Integrated Antenna Technology," Proceedings of MIKON 96, pp. 69-72, May 27-30, 1996, Warsaw, Poland, May 27-30, 1996, (C. Pobanz and T, Itoh).

"Synthesis of Absorbing Boundary Condtion with Digital Filter Bank," IEEE MTT-S 1996 International Microwave Symposium Digest, pp.1043-1046, June 17-21, 1996, San Francisco, CA, (C. N. Kuo, T. Itoh and B. Houshmand).

"A 10-Element Active Lens Amplifier on a Dielectric Slab," IEEE MTT-S 1996 International Microwave Symposium Digest, pp.1119-1121, June 17-21, 1996, San Francisco, CA, (A. Perkons and T. Itoh).

"Applications of Time-Domain Simulation to Microwave Circuits," 1996 Progress in Electromagnetics Research Symposium (PIERS), p.76, July 8-12, 1996, Innsbruck, Austria (C.-N. Kuo, B. Houshmand and T. Itoh).

"Improved Phase Noise Active Antenna Arrays Using DR-Coupled Oscillators," 1996 Progress in Electromagnetics Research Symposium (PIERS), p.302, July 8-12, Innsbruck, Austria (S. T. Chew and T. Itoh).

"Characterization of Leaky Wave Antenna and Active Gain Enhancement," Proc. 26th European Microwave Conference, pp.579-582, Sept.9-12, 1996, Prague, Czech. (M. Chen, H. Z. Chan, B. Houshmand and T. Itoh).

"High Active Device Density Quasi-Optical Amplifier," Proc. 26th European Microwave Conference, pp.208-210, Sept. 9-12, 1996, Prague, Czech. (S.-T. Chew and T. Itoh).

"Application of the FDTD Method to the Analysis of Housing Effects in Active and Nonlinear Microwave Circuits," Proc. 26th European Microwave Conference, pp.537-539, Sept. 9-12, 1996, Prague, Czech. (C.-N. Kuo, B. Houshmand and T. Itoh).

"Surface Wave Excitation of a Dielectric Slab by a Yagi-Uda Slot Array Antenna," Proc. 26th European Microwave Conference, pp.625-628, Sept. 9-12, 1996, Prague, Czech. (A. Perkons and T. Itoh).

"A Two-Dimensional Retrodirective Array Using Slot Ring FET Mixers," Proc. 26th European Microwave Conference, pp.217-220, Sept. 9-12, 1996, Prague, Czech. (C. Pobanz and T. Itoh).

"Two-Dimensional vs. Three-Dimensional Quasi-Optical Active Antennas," Proc. International Symposium on Antennas and Propagation (ISAP), pp.1241-1244, Sept. 24-27, 1996, Chiba, Japan (S.-T. Chew, A. R. Perkons and T. Itoh).

"Full-Wave Simulation of Nonlinear Microwave Circuits," Proc. 4th International Workshop INMMC'96, pp.25-28, Oct. 9-11, 1996, Duisburg, Germany (C.-N. Kuo, B. Houshmand and T. Itoh).

"Analysis of Crosstalk in Packaged Microwave Circuits," Proc. 5th Topical Meeting on Electrical Performance of Electronic Packaging, pp.193-195, Oct. 28-30, 1996, Napa, CA, (C.-N. Kuo, B. Houshmand and T. Itoh).

"Simulation of Active Microwave Structures by FDTD Method," Proc. Microwave Workshop and Exhibition (MWE), pp.81-84, Dec. 10-12, 1996, Yokohama, Japan, (C.-N. Kuo and T. Itoh).

Journal Papers Submitted

"FDTD Analysis of a Metal-Strip-Loaded Dielectric Leaky-Wave Antenna," submitted to IEEE Trans. Antennas and Propagation, (M. Chen, B. Houshmand and T. Itoh).

"Full-Wave Analysis of Packaged Microwave Circuits with Active and Nonlinear Devices: A FDTD Approach," accepted by IEEE Trans. Microwave Theory and Techniques, (C.-N. Kuo, B. Houshmand and T. Itoh).

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(2) Scientific Personnel and Degrees

T. Itoh, Principal Investigator
Y.Qian, Post Doctoral Research Engineer
C. Pobanz, Research Assistant
A. Perkons, Research Assistant (AASERT)
S. T. Chew, Research Assistant Ph.D. 1996
C. N. Kuo, Research Assistant
M. Chen, Research Assistant
W. Deal, Research Assistant (AASERT)

Honors and Awards

None

(3) Reports of Invention

None

(4) Scientific Progress and Accomplishment

1. Active Integrated Antennas - S. T. Chew and T. Itoh

Several practical issues have been investigated on the active integrated antennas. In one project, we studied a way to increase the density of the active devices in the structure without substantially increasing the required real estate. Therefore, the power density per unit cell in the active antenna array can be increased. In another project, an effort has been spent for improving the phase noise in oscillating type active integrated antenna. This was accomplished by insertion of dielectric resonator to stabilize the oscillation frequency.

2. Characterization of Leaky Wave Antenna and Gain Enhancement - M. Chen and T. Itoh

FDTD (Finite Difference Time Domain) method has been applied for the first time for a realistic leaky wave antenna made of periodically perturbed dielectric waveguide including the transition from the rectangular waveguide at W band. In parallel to this effort, we have applied the concept of active integrated antenna into the leaky wave structure. By providing the gain to the guided wave in the leaky wave antenna, the effective aperture of the antenna has been increased resulting in a narrower beam and an active gain.

3. All Optical Control of Beam Steering Active Integrated Anenna - W. Deal and T. Itoh

Based on the unilateral injection locking of an active oscillating array, the beam can be steered by changing the dc bias to each oscillator element. The phase difference between the free-running frequency and the reference frequency can be controlled by the dc bias while the oscillation frequency is locked to the reference frequency signal injected. In the past, we have used optical fiber to provide the reference signal which modulates the laser source to the antenna remotely located. Under the present project, the control signal is also transmitted remotely by optical fiber. We have designed and built a photodetector circuit which control the bias voltage of the transistor in the active antenna so that the free running frequency can be changed.

4. Comprehensive Electromagnetic Analysis of Active Microwave Circuits - C.-N. Kuo and T. Itoh

We have been developing a comprehensive electromagnetic simulation capability for active microwave circuits such as oscillators and amplifiers. In the conventional FDTD, the absorbing walls are used to limit the computational space into a manageable size. High performance absorbing walls are even more important in the Extended FDTD to handle active microwave circuits, because the fundamental frequency as well as harmonics must be absorbed well. Digital signal processing techniques have been applied for this purpose. A digital filter bank was used to synthesize the absorbing boundary condition with excellent results.

5. Planar Active Lens for 2-D Quasi-Optical Circuits - A. Perkons, Y. Qian and T. Itoh

We have successfully demonstrated an active lens amplifier on a dielectric slab-beam waveguide (DSBW). Based on this experience, we have designed the most critical element, Yagi-Uda slot antenna to be used for 94 GHz structure to be developed jointly with TRW. (See Technology Transfer section of this report). The design is based on an extensive numerical calculation based on the FDTD algorithm with the numerical results confirmed by the X band experiment.

In the second effort, we have developed a TE surface wave power combiner with a planar 10-element active lens amplifier. To this end, we have developed a dipole antenna sandwiched between dielectric slabs. TE surface wave is known to have less attenuation than the TM wave which was used in the previous version. From the X band demonstration, we have obtained an uncommonly large bandwidth of 56% with system gain greater than 7 dB. At 7 GHz, the output of the combined power is 17.6 dBm at 1 dB compression point. The power combining efficiency is about 60%.

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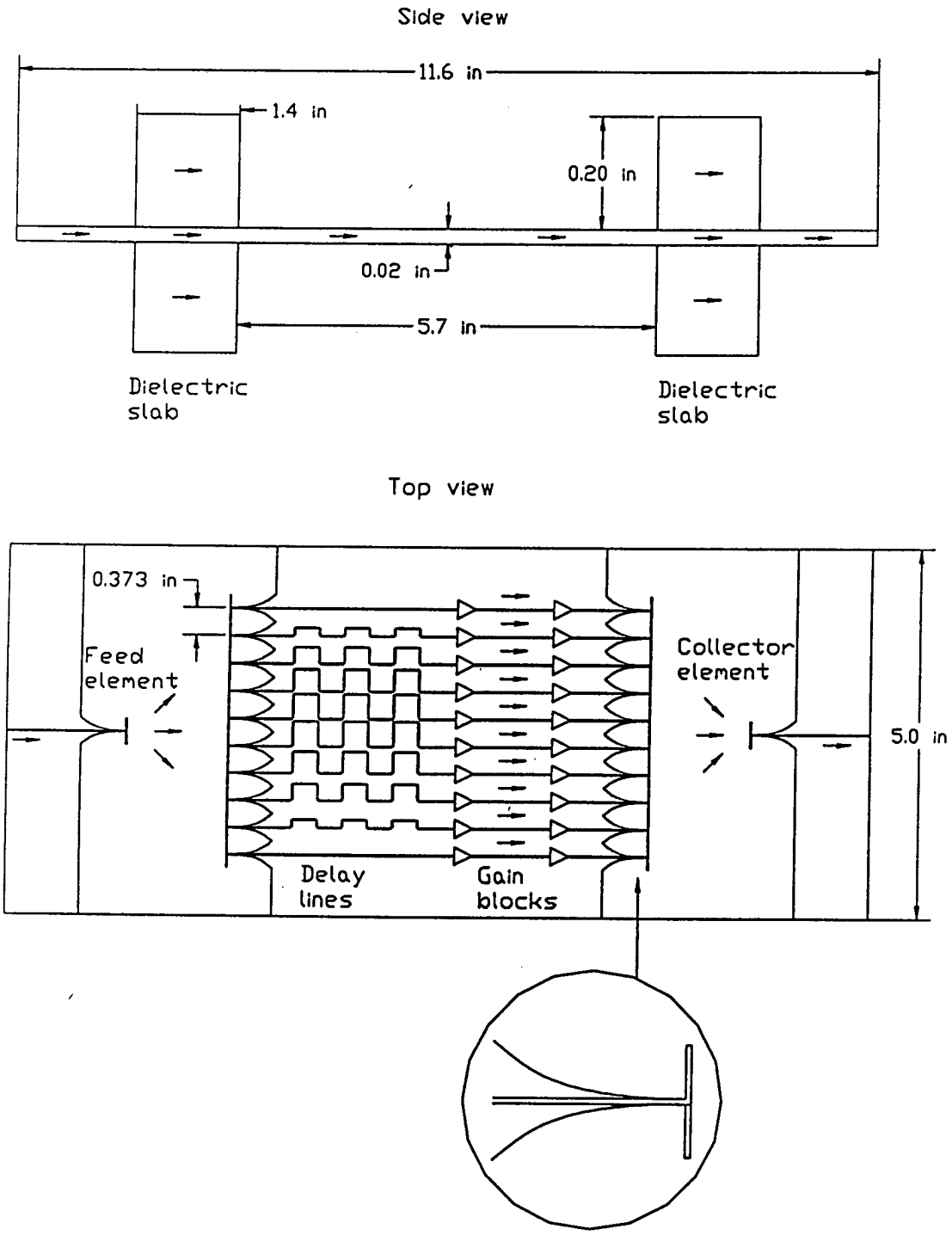

Fig. 1. TE mode slab-beam lens amplifier. Gain blocks and microstrip lines are on top side of thin substrate sandwiched between dielectric slabs. Microstrip ground planes and exponential tapers are on bottom. Half of dipole is on top side and the other half is on the bottom side.

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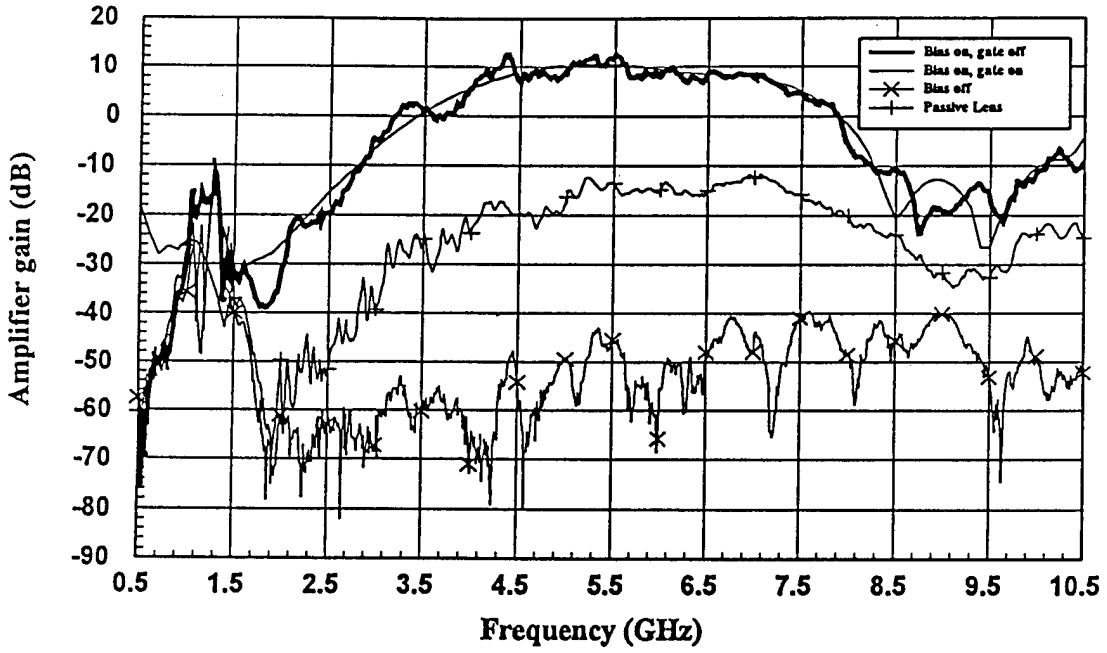

Fig. 2. TE mode slab-beam lens amplifier gain versus frequency. Gain is greater than 7 dB over a 56% bandwidth centered at 5.6 GHz. Insertion loss of a passive lens is included for reference.

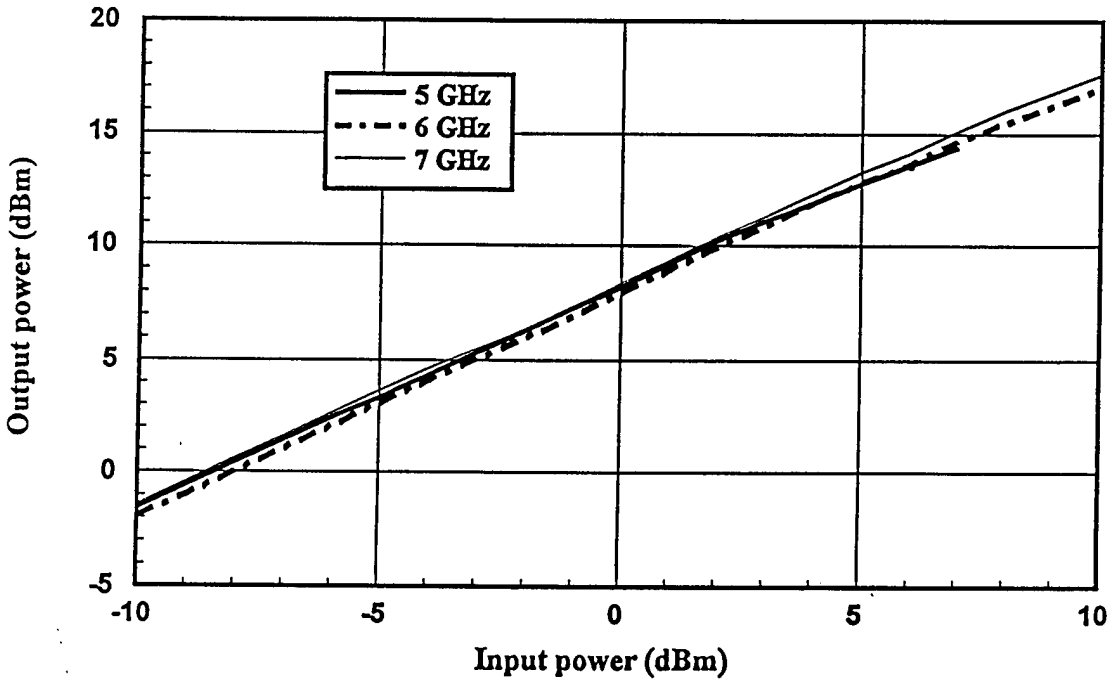

Fig. 3. Output power plotted against input power. Output power at 1 dB gain compression is 14.4 , 17.1, and 17.6 dBm at 5, 6, and 7 GHz, respectively.

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(5) **Technology Transfer**

- Under the DARPA MAFET Phase III program, TRW is developing a 2D Quasi-Optical Power Combiner at W band based on the design and know-how developed at UCLA under this ARO program. UCLA provides all the design parameters according to the practical implementation issues at 94 GHz taken into account.

- T. Itoh organized a NATO Advanced Summer Institute on New Directions in Terahertz Technology in France on July 1-11, 1996. He also gave a lecture on the active integrated antennas. This ASI was attended by about 80 scientists and engineers from NATO countries and a few from non-NATO coutries.

- T. Itoh gave a presentation on active integrated antennas at NATO Workshop on Smart Antenna Structures in Brussels on November 25-26, 1996. The workshop was organized by French Ministry of Defense and was attended by a large number of government, industrial and academic personnel from US and other NATO countries.